Clean Air Conference ‘Analysis and Solutions: Responding to the Clean Air Challenge

HEICCAM
Clean Air Research Network

Empirically measuring indoor air pollutants with low-cost and high-cost sensors in a low-carbon home retrofit

Prof Rajat Gupta, Dr Sahar Zahiri, Oxford Brookes University
Prof David Oram, Dr Charel Wohl, University of East Anglia
Prof Ruth Doherty, Dr Malina Modlich, University of Edinburgh
Prof Mike Davies, Prof Anna Mavrogianni, Dr Giorgos Petrou, University College London
Dr James Milner, LSHTM
Dr Mohammed Mead, Imperial College London

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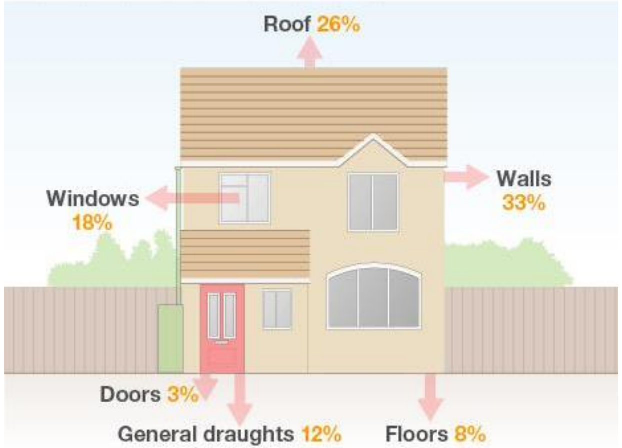
Outline of presentation

- **Context**
- **Study overview**
  - Purpose of the study
  - Case study: retrofitted low carbon dwelling in Oxford
  - Methods
- **Findings**
  - Monitoring using low-cost sensors
  - Passive sampling using high-cost sensors
- **Final thoughts**

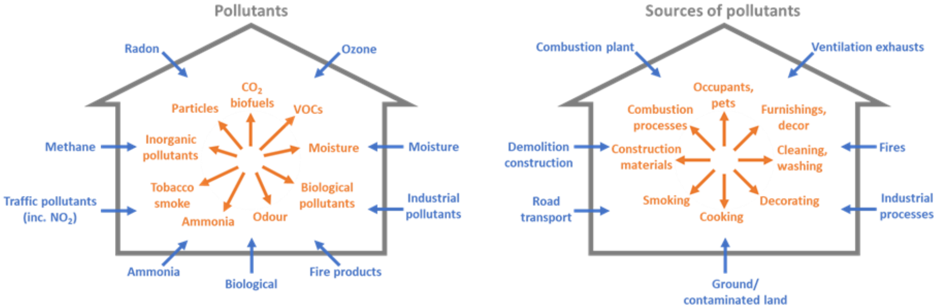
Context

- To reduce heating demand, retrofit measures increase airtightness, which also reduces removal of indoor pollutants.
- In the UK, there is limited empirical data to quantify indoor well-being pollutants and how they vary over time, and by building to building.
- There is also limited empirical data on the effect of home energy retrofits on indoor air quality.
- The impact of poor IAQ on health and wellbeing is less understood, especially for vulnerable groups.
- This is what the HEICCAM research network seeks to address.



Heat loss in a typical uninsulated dwelling

Source: Energy Saving Trust



Adapted from Kukadia and Upton, 2019

Overview of the study

Study aims

- To characterise and understand factors affecting concentrations of indoor air pollutants (IAPs) in an energy-retrofitted dwelling in Oxford in relation to
  - building characteristics and ventilation, and
  - how it linked to personal activities of occupants.

- To identify the implications of using **low-cost** (and lower accuracy) sensors versus (via sampling techniques) **high-cost** (and higher accuracy) devices.
  - Test air pollution measurement and monitoring methods in situ.
  - Collect data on the relevant behaviour of residents to provide more detailed context to the findings.

Case study dwelling

- Three bedrooms end-terrace house (92 m^2)
- Open-plan kitchen and living room located on the ground floor, main bedroom located on the first floor.
- Occupied by a retired couple (>65years) all the time. Environmentally conscious. Active in local community energy group.
- EPC rating B
- **Well insulated** building fabric and windows.
- **Electrification of heating**: Air Source Heat pump
- **Electrification of cooking** (removed gas connection)
- **Naturally ventilated:**
  - *Purge ventilation* in the morning and early evening.
  - *Background ventilation* through window trickle vents left open 24/7.
  - *Boost ventilation* - Extractor fan in toilet, Cooker hood in kitchen

Mixed Methods approach

- **Dwelling characteristics:** Energy Performance Certificate (EPC).
- **Monitoring IAPs:** low cost sensors between 6th - 29th Feb 2024:
  - Indoor temp, RH, CO_2, $PM_{2.5}$, PM_{10} and VOC (Isobutylene) at one-min interval, using internet-enabled **Airthinx** devices
  - Main bedroom, living room and kitchen
- **Passive sampling:** carried out between 12th Feb (evening) and 14th Feb (morning) using UEA's Mass Spectrometers high resolution devices including
  - Canister 'average' sampling (two nights and two days)
  - 'Tracer release experiment' undertaken between 12:30pm- 4:30pm on 13th Feb 2024
- **Personal activity diary:** carried out between 12th -18th Feb 2024 to understand the links between occupants behaviours (e.g. cleaning and personal care activities) and concentration of IAPs.
- **Household survey:** carried out before heat pump installation that provided contextual insights.

Airthinx device

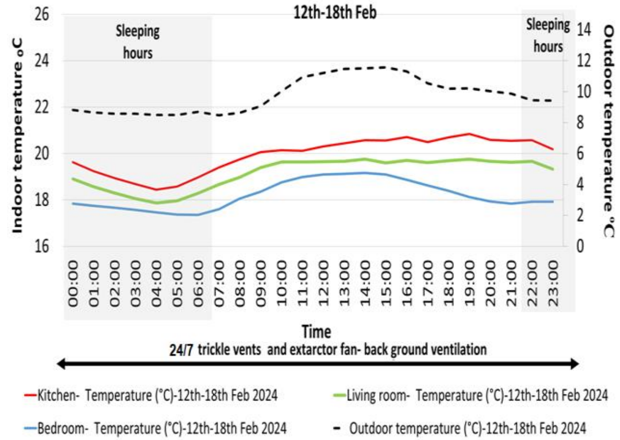
Passive sampling using mass spectrometers

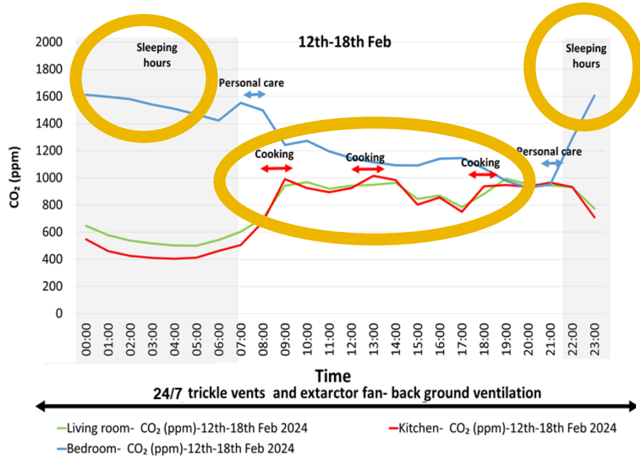
- Speciated VOCs measured by a Vocus-PTR mass spectrometer using air bag spot samples during
  - ‘Canister samples’ reflecting an 8-hour average concentration between 12th-14th Feb 2024.
  - ‘Tracer release’ experiment carried out in thee living room/ kitchen area on 13th Feb 2024 between 1:30 pm and 4:15 pm
- During ‘tracer release’ experiment, residents carried out following activities over half an hour:
  - Using skin care products between 1:30 pm and 1:37 pm, which included wrinkle cream, moisturiser, hand cream, hand sanitizer.
  - Using cleaning products between 1:43 pm and 2:00 pm, which included Viakal sink cleaner, bleach floor cleaning, window cleaning, furniture polish, stain removal.
- Purge ventilation after the last cleaning activities undertaken.

Findings

Indoor temperature and CO_2 levels (Airthinx)

- Indoor environment varied across the three rooms.
- Mean daily indoor temperature ranged between 19.1ºC and 19.6ºC in the living room and the kitchen.
- Indoor temperature in the bedroom was lower, with mean daily indoor temperature of 17.6ºC.
- Likely to be due to occupants' thermal preferences and more exposed positioning of the bedroom.
- Mean daily indoor CO_2 concentrations were found to be relatively high in the bedroom, reaching a peak of 1,600ppm overnight.
- In contrast, CO_2 concentrations in the living room and the kitchen peaked during cooking time, ranging between 950ppm and 1012ppm respectively.





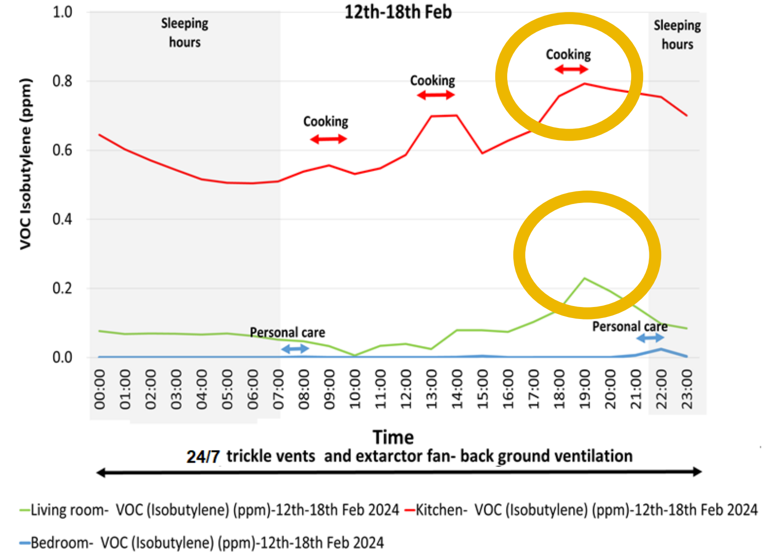
Indoor VOC (Isobutylene) and PM levels

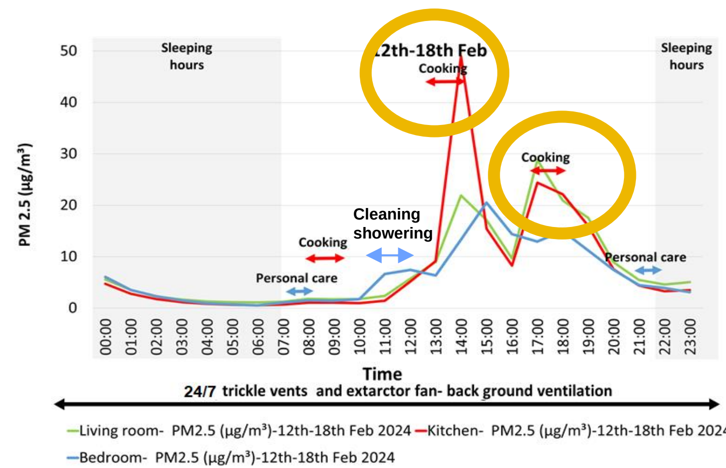
- Indoor VOC (isobutylene) levels were found to be higher in the open-plan kitchen and living room, with mean daily reaching a peak of 0.8ppm and 0.2ppm respectively at 7:00 pm.

- This was due to cooking and cleaning activities that were undertaken in the open-plan kitchen.

- Similarly, indoor $PM_{2.5}$ levels spiked in the kitchen and the living room during daytime due to cooking activities, reaching peaks of 50µg/m³ and 30µg/m³ respectively.

- Indoor PM_{10} levels followed a similar pattern as $PM_{2.5}$ levels across the three rooms between 12th and 18th Feb 2024.





Passive sampling

12th -14th Feb 2024

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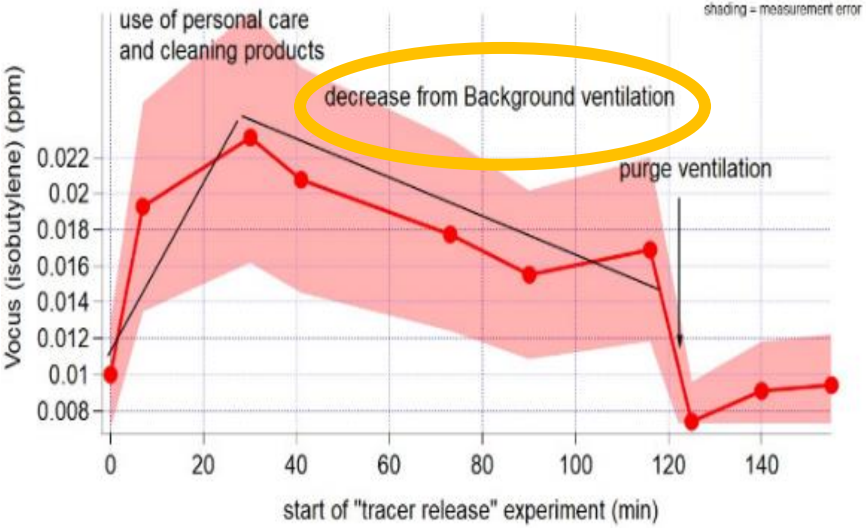
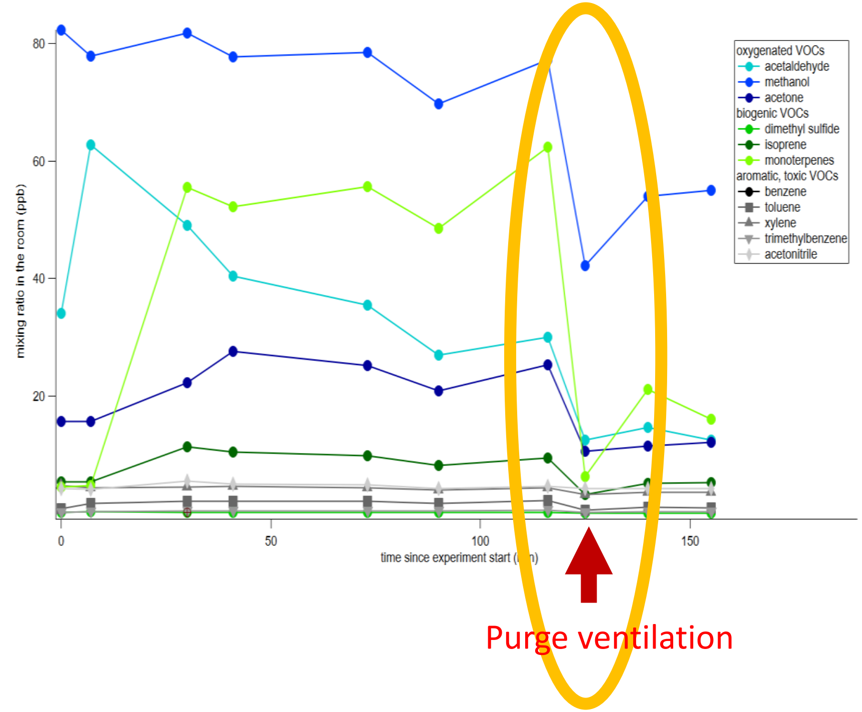
Canister sampling

Canister samples				
Time period	Location	Benzene (ppb)	Toluene (ppb)	Xylene (ppb)
Night	Living room	3.6	0.7	0.5
Night	Bedroom	3.7	0.7	0.5
Day	Living room	5.5	0.9	0.8
Day	Bedroom	5.0	0.7	1.4

- Canister samples confirmed the rise in indoor VOCs levels in the kitchen and living room during daytime.
- Benzene concentrations were found to be higher than DEFRA national air quality objectives reaching to 3.7ppb (0.0037ppm) in the bedroom overnight
- In contrast, it reached to 5.5ppb (0.0055ppm) in the living room during daytime.
- Other VOCs were found to be below exposure limits as per UKHSA guidelines.

Tracer release experiment





- ‘Tracer release’ experiment revealed slow removal of some specific VOCs through background ventilation.
- In contrast, it showed fast removal of all the speciated VOCs by purge ventilation.

Final thoughts

- The rapid removal of all speciated VOCs through purge ventilation, and the slower removal of specific VOCs via background ventilation, highlight the importance of integrating effective ventilation and air purification strategies to maintain a healthy indoor environment.

- Emphasises the need for enhanced ventilation systems that align with occupant activities, especially in energy-retrofitted homes.

- Findings demonstrate the added benefit of deploying both high-cost and low-cost sensors simultaneously to gain complementary insights, particularly in terms of speciated exposure limits.

- Limited understanding of the health impacts of indoor air pollutants on occupants - especially vulnerable groups - points to the need for further research to develop robust indoor air quality management strategies for energy-retrofitted homes.

Thank you for your attention.

Prof Rajat Gupta, rgupta@brookes.ac.uk